AN OCCURRENCE OF GREENSTONE SCHISTS IN THE SAN JUAN MOUNTAINS, COLORADO.[1]

IN the course of a recent examination of the Needle Mountains quadrangle by the United States Geological Survey, a series of metamorphic rocks was encountered that differs in many respects from those occurring near by in the Animas Canyon, which have been considered to be of Archean age.

The region is near the southwestern limits of the San Juan Mountains of southern Colorado, which are made up largely of Tertiary volcanic rocks. In that portion which is known locally as the Needle Mountains, and which lies in parts of San Juan and La Plata counties, the younger lava flows and breccias are absent, and ancient crystalline or metamorphic rocks have been exposed by the dissection of a dome-like uplift, in which all of the sedimentary formations, as late at least as the last of the conformable Cretaceous beds, have been involved. These rocks, which are all of pre-Cambrian age, are granites, schists, and quartzites; the ones to be described, which may be referred to conveniently as greenstones, occur at the southern side of the uplift.

During a hurried visit to the region in 1901, one of the members of the party, who was familiar with the Marquette and Menominee greenstones, called attention to the similarity of these rocks to those of the Lake Superior region. In the next field season a more detailed study was made of the complex, and in the laboratory specimens of the Needle Mountains rocks were compared with those collected by the late G. H. Williams in the Marquette and Menominee localities, as well as with specimens described by Cross from near Salida, Colorado, in the Arkansas Valley.

Occurrence of the greenstones.—The greenstones are found for a little over seven miles in a north-and-south direction on both sides of Vallecito Creek, midway between its head and the point where it joins Pine River. From east to west the area occupied by the greenstones is not more than two and a half miles wide at most. To the

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north and east they are sharply bounded by fault contacts with sedimentary rocks of pre-Cambrian age, or have been intricately infolded with them; another fault separates the greenstones on the west from a large mass of granite, while to the southward they disappear beneath the Paleozoic sedimentaries.

Many of the exposures are of well-banded schistose rocks, and it was only natural that they were at first assumed to be a part of the great Archean complex of schists and gneisses known to occur near by in the Animas Canyon. On closer study, however, it soon became evident that there were marked differences between the two series of rocks. The Irving formation, as the greenstone complex has been named, from Irving Peak, was found to consist, not only of the schists first observed, but also of massive basic rocks sometimes possessing a porphyritic structure, others partly mashed or brecciated, and a few distinctly granular, while no well-defined system of bedding or stratification could be made out. All of the rocks are of a dull greenish color and appear to have undergone extensive alteration. At two places massive quartzite was found, and at a number of localities extremely siliceous schists occur, some of which have undoubtedly been derived from quartzites through dynamic metamorphism, while others must have been originally granites or closely allied rocks. A single band of siliceous magnetite some fifteen feet in thickness was also observed near the northern end of the series.

Most of the exposures are a dull leaden-gray or green, in sharp contrast to the lighter-colored granites and quartzites to the north and west, and their somber tones add to the gloomy aspect of the valley sides which have, in many places, been swept by destructive forest fires. The dull monotony is occasionally relieved by dikes of bright red granite porphyry or pegmatite near the contact with the granite mass to the westward. The only marked variations in the Irving formation itself are the comparatively rare occurrences of a very light gray gneiss or mashed quartzite.

Description of the rocks.—The majority of the rocks found in the Vallecito section display considerable textural variety, but appear to be o nearly the same mineralogical composition. Hornblende, chlorite, epidote, and rarely biotite can be recognized megascopically in nearly all, and usually these dark minerals appear to be in excess

of the lighter silicates; what feldspar there is has evidently been much altered. The most significant features of the rocks in different parts of the complex are the variations in texture and structure which are conspicuous in the field and still more so when the rocks are examined microscopically. As will be shown later, these are due partly to original textural differences in the rocks themselves, and in part to their dynamic metamorphism that has produced, in some instances, finely laminated schists in which all traces of original structure have been obliterated.

In the field and laboratory two distinct kinds of massive rocks have been recognized, and transitions between them and the schists may be followed in many cases. Rocks of the first kind are granular and of a medium texture. The second consist of porphyries with phenocrysts of eldspar and hornblende in a very fine-grained groundmass, or are extremely dense, without phenocrysts and resemble the finer-grained diabases. A number of rocks of intermediate textures have been found, but the two groups may be considered as fairly well defined for purposes of description.

Massive granular greenstone or metagabbro.—Occurrences of strictly granular rocks are not numerous. The best examples have been found in a restricted area which includes Irving Peak and its southwestern flanks near the northern limits of the complex. The texture of these rocks is practically the same as that of many medium-grained gabbros, the only differences being that laths of plagioclase cannot be made out, and that the dark amphibole, although it appears to be in the form of blades or lath-shaped crystals, is, in reality, fibrous. The average rock is moderately coarse, even-grained, but specimens from the summit of Irving Peak show a tendency toward the formation of fine-grained segregations richer in hornblende. On fresh surfaces the color is a dark bluish- to greenish-gray.

A microscopical examination shows at once that the rocks are more or less metamorphosed. The chief constituents are hornblende, plagioclase, and generally a very little biotite and magnetite. The plagioclase is seldom fresh enough to permit of an exact determination of its character, but the large extinction angles indicate labradorite. The feldspar and hornblende are present in about equal quantities in large irregular patches rather than grains. The

feldspars seem, in many cases, to have possessed crystal boundaries and were often typically lath-shaped. At present, even in the freshest specimens, they are much altered to calcite, muscovite, zoisite, and epidote, and individual grains have been bent and broken, but are not crushed. Hornblende, which is, as a rule, quite fresh, is of the pleochroic fibrous variety, uralite, and there can be little doubt as to its secondary origin; it sometimes appears almost massive, but the borders are extremely ragged, and minute blades and needles are scattered throughout the rock and often penetrate the feldspar areas. Biotite is unimportant and occurs more in the nature of an accessory.

Although from their mineralogical composition these rocks might be classed as diorites, and although no trace of pyroxene has been found, still from their resemblance to rocks of other regions, especially in the Menominee district, where all the stages in the change from gabbro to hornblende rock may be observed, they are to be regarded as gabbros in a rather advanced state of alteration.

Porphyritic and fine-grained greenstones.—The mineralogical composition of the porphyries and greenstones of finer grain is essentially the same as that of the granular rocks, the hornblende being possibly a little more prominent. Alteration, however, is generally more advanced, but strangely enough the original structures are often well preserved, even where the feldspars have been completely saussuritized or changed to other secondary minerals, and the dark silicates have been altered to chlorite. The structure which seems to prevail in all of the finer-grained rocks is the ophitic, so typical of diabase, in which laths of plagioclase lie, as it were in a groundmass of pyroxene and magnetite. In the case of the greenstones the outlines of the feldspar laths are distinct, and the crystals often appear to radiate from a central point. What should correspond to pyroxene is, in the greenstones, either a mesh of uralite needles or chlorite, together with smaller grains of undeterminable feldspar and occasionally quartz. Here, there can be no doubt that the rocks were derived from diabase or diabase porphyry by the well-recognized change of pyroxene to hornblende and the alteration of labradorite to saussurite, accompanied by the development of epidote and calcite.

Between these altered massive rocks and the finely laminated schists, a series of rocks may be found which illustrates the various stages of dynamic metamorphism, and satisfactorily proves the close relation of the schists and massive greenstones. The bending and fracturing of the feldspars is followed by more complete crushing, and the hornblende is broken up and redistributed in small parallel blades through the rock. In extreme cases recrystallization has probably taken place, and the minerals in such rocks are, as a rule, much fresher than in many of the less mashed varieties.

Greenstone schist.—The more or less completely schistose rocks which make up the major part of the Irving series differ but little from many of the schists of the Archean. They are fine-grained and well laminated and of a dark greenish-gray color. The microscope shows them to be made up of pleochroic green hornblende in excess of finely granulated feldspar, and usually biotite, a little quartz, and magnetite. The parallel arrangement of the minerals, especially of the blades of hornblende and biotite, is very striking. Feldspar sometimes occurs merely as interstitial grains between the dark silicates, but usually it is present as a fine mosaic in long-drawn-out lenses or bands. In some cases chlorite has completely replaced hornblende, and muscovite has been developed at the expense of part of the feldspar.

Siliceous schists.—At a number of localities within the greenstone area schists and gneisses of a much less basic character have been found. They are light gray or nearly white in color, the dark silicate is biotite, and the feldspar, when recognizable, orthoclase and microcline, with only small quantities of plagioclase. Quartz is abundant, and the microscope shows that magnetite, muscovite, and rarely augite or hornblende, may occur as accessories. In all cases the mashing has been sufficient to destroy original textures and develop an excellent schistosity or lamination. Except in one or two doubtful cases, to be noted later, these rocks appear to have been formerly intruded into the greenstones as granites, and subsequently to have shared with the older rocks in the mashing and deformation of the region.

The exceptions just mentioned are some unusually siliceous rocks whose relations to the greenstones are not altogether clear.

Like the others, they are very completely mashed and contain both feldspar and biotite, but the amount of quartz is largely in excess of that of all the other minerals. The occurrence of massive quartzite with the Irving greenstones has already been referred to, and it seems more than likely that these siliceous schists are quartzites that lay within zones of great mashing and suffered with the rest of the rocks.

Structure.—It has not been possible to find any evidence of original bedding in the Irving greenstones, although frequently, on account of their schistosity, the rocks appear to be stratified. This banding, though predominant, is not a constant feature, and transitions may be observed from schists to unmashed rocks which have the composition and textural characteristics of intrusives. In addition to the schistosity, which is generally vertical and with a northwest-southeast strike, the massive greenstones, more especially near their contact with the Algonkian conglomerates and quartzites, have been fractured and brecciated. These conditions were probably brought about at the time that the shearing and complicated infolding took place between the Algonkian sediments and the Irving greenstones. In a very few cases it has been possible to recognize dikes of compact greenstone cutting either coarser rocks of the same sort or siliceous schists.

The petrographical examination of the rocks failed to show that they had occurred as surface flows, all of the characteristics being those of intrusive rocks. The only possible exceptions are certain rocks near the eastern border of the greenstone area. They are considerably altered and have been mashed, and their field appearance suggested that they were flow-breccias or tuffs, with fragments or drawn-out lenses of greenish porphyry lying in a dense cementing material of a darker color. Unfortunately, decomposition has proceeded too far for a microscopical examination to be of value; secondary minerals are about the only ones that can be made out, but the texture suggests crushing or mashing. The occurrence of these rocks seems to be restricted to the region immediately adjoining the contact with the Algonkian conglomerates, where, as has been said, complicated infolding and fracturing have taken place, and it is more reasonable to suppose that these rocks are friction breccias, subsequently mashed, than that they are of pyroclastic origin.

Age of the greenstones.—The oldest rocks in contact with the Irving greenstones are the conglomerates and quartzites of the Algonkian to the north and east. The actual relations of the two formations have been obscured by faulting or infolding, but the greater age of the Irving is shown by the quantities of schistose and massive greenstone pebbles in the lower portions of the Algonkian conglomerate. The character of these pebbles also supplies information in regard to the age of the mashing of the Irving greenstones, the greater part of which evidently took place before the deposition of the conglomerate. Later movements occurred after Algonkian time and resulted in the further fracturing and mashing of the greenstones, as well as the lower portions of the conglomerate.

As to the lower age limits, little can be said with certainty, except that the rocks have been less affected by dynamic metamorphism than any that are known to occur in the neighboring Archean areas. They have been regarded as of early Algonkian age, separated from the younger Algonkian sediments by an erosion interval of unknown extent. That the Irving, as now exposed, represents but a small part of a much greater series of rocks which formerly existed seems certain. Evidence of this is to be found in the great thickness of Algonkian conglomerates, for, although greenstone pebbles are conspicuous in many places, quartzite débris is more abundant, and lenses or beds of magnetite or jasper bowlders are often seen high up in the section, all of which indicates the destruction of an earlier terrane, the only traces of which that may now be recognized being the comparatively rare beds of quartzite and magnetite associated with the Irving greenstones. These same remnants are believed to be inclusions in the diabase and gabbro which intruded sediments that have since been worn down to supply the materials for the younger series of quartzites.

Comparison with rocks of other localities.—The collection of rocks from the Menominee and Marquette regions made by the late G. H. Williams, and described by him in a bulletin of the United States Geological Survey,[1] has been examined in connection with the present study, and a certain similarity between the two series of rocks

[1] G. H. Williams, "The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan," *Bulletin No. 62* (1890), U. S. Geological Survey.

has been found in a number of cases. Professor Williams states that "there is considerable evidence to show that the greenstones, both of the Menominee and Marquette regions, solidified at the surface, under subaërial or subaqueous conditions." There are, however, a number of instances where the rocks are clearly intrusive, and it is these that the Irving greenstones most closely resemble. The character of the metamorphism appears to have been the same in both regions, and the rocks from which the greenstones were derived were undoubtedly very similar. The most important difference is that tuffs and surface flows have been recognized in the Lake Superior complex, while no rocks of this nature have been seen in the Irving. Flows or fragmental deposits of igneous origin may, of course, have been originally present, but all traces have been destroyed.

The Irving greenstones and those occurring near Salida in the Arkansas Valley, some 125 miles to the northeast, possess a number of common characteristics; in fact, the description by Mr. Cross[1] of the hornblendic members of the Salida rocks might be applied directly to those in the Needle Mountains. In both localities granular hornblendic rocks occur and also denser rocks in which the microscope reveals an ophitic structure. The only rocks found in the Salida section which differ greatly from those of the Irving are ones which are in some instances sufficiently well preserved to indicate a structure and composition like that of rhyolite, and which in extreme cases of metamorphism suggest finely mashed micaceous quartzites. There are not sufficient data in regard to the field occurrence of these rocks to make it possible to say whether they were originally surface flows or intrusives, but in regard to the series as a whole, Cross is inclined to believe that they represent "a great series of surface lavas erupted in Algonkian time."

In a recent monograph of the United States Geological Survey, Bayley[2] has redescribed the greenstones of the Menominee region under the name of "Quinnesec schists" and has referred them to

[1] On a Series of Peculiar Schists Near Salida, Colorado. *Proceedings of the Colorado Scientific Society*, Vol. IV (1893), pp. 286–93.

[2] W. S. BAYLEY, "The Menominee Iron-Bearing District of Michigan," *Monograph 46* (1904), U. S. Geological Survey.

the Archean. The greenstones of the San Juan Mountains are most clearly associated with Algonkian rocks, and, aside from their lithological similarity, there seem to be no good reasons for attempting to correlate such distant occurrences as the Quinnesec and Irving schists.

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